

Slide 1



PRESENTATION NOTE: This presentation can take 30 to 45 minutes.

A key goal of NASA's scientific research is the search for life in the universe.* Kepler is NASA's first mission dedicated to detecting Earth-size planets orbiting in the habitable zone of Sun-like stars.

Kepler launched on March 6 of 2009, and (as of July 2015) Kepler has confirmed 1,030 exoplanets with thousands more candidates being evaluated!

** "NASA's strategic objective in astrophysics is to discover how the universe works, explore how it began and evolved, and search for life on planets around other stars." NASA Science Mission Directorate*

Slide 2



Kepler

How many Earths?

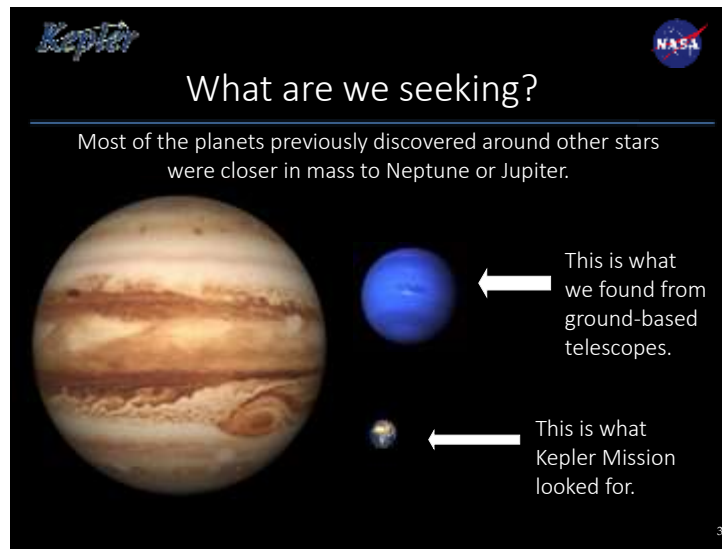
How common are Earth-size planets in the habitable zone of Sun-like stars?

NASA's Kepler Mission aims to get a more precise answer to this question!

Credit Earth: NASA Goddard Space Flight Center <http://viableearth.nasa.gov/>

Previously, scientists could only guess at how many Earth-size planets might exist. Then, on March 6th, 2009 NASA launched the Kepler spacecraft.

We have a much better idea with the findings from NASA's Kepler Mission, which ended its four-year mission in May 2013 with flying colors. Much of the data that was collected during that 4-year period is still being analyzed. The Kepler spacecraft has been repurposed to make discoveries in a new mission named K2.

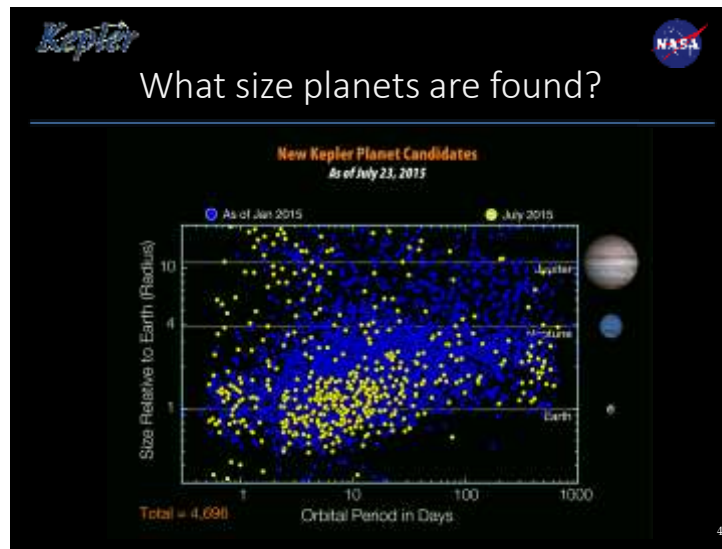


Most of the planets that have been found are those similar in size and mass to Neptune or even larger. In fact, most of the first exoplanets discovered from ground-based observing were the size of Jupiter or bigger! It was not possible to find small planets from ground-based telescopes. The Kepler Mission was designed to find the smaller Earth-size planets.

WHAT'S ON THE SLIDE: This graphic shows a scale size comparison of Jupiter, Neptune, and Earth. NASA's Cassini spacecraft imaged Jupiter as it fly by the planet on its way to Saturn. NASA's Voyager 2 imaged Neptune during its historic flyby in 1989.

EXTRAS: The relative mass of Jupiter to Earth is comparable to the relative mass of a bowling ball and a marble. A planet also has to have the right mass to support life as we know it. Too little mass and it probably won't have much of an atmosphere. Too much mass and it may have a thick atmosphere thousands of miles deep like Jupiter, Saturn, Uranus, and Neptune.

Jupiter's diameter is eleven times greater than that of the Earth, and it has over 300 times the mass.



This is a chart shows the sizes and orbits of all of the planet candidates discovered by Kepler as of July 23, 2015. As astronomers find more and more planets, they discover that the average size of these distant worlds is becoming smaller. Smaller - and rocky - worlds are turning out to be very numerous indeed!

What is the "radial velocity" method?

Radial Velocity

Scientists use the radial velocity or "wobble" of a star to detect planets.

When an unseen planet tugs the star back and forth...

Astronomers can detect shifts in the spectral fingerprints of the star.

Radial velocity reveals large planets orbiting stars, but is not sensitive enough to detect Earth-size planets.

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Using ground-based observatories, scientists measure the Doppler shift of stars to find the planets that tug upon them..

Here is how it works:

[Click space bar]

an unseen planet tugs the star back and forth...

[Click space bar]

light from the star shifts slightly to the red as the star moves away from the observer..

[Click space bar]

slightly to the blue as it moves toward the observer.

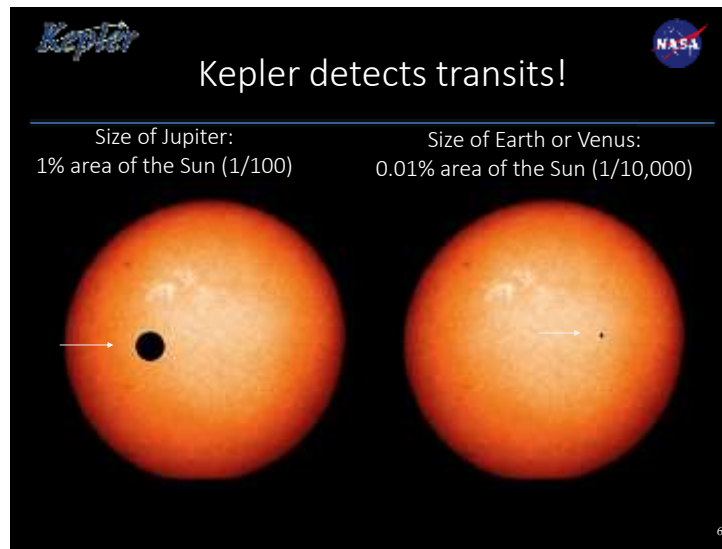
[Click space bar]

Astronomers can detect these shifts by very carefully observing the spectra (or colors) of the stars.

WHAT'S ON THE SLIDE: Cartoon animation of how the "radial velocity" method of detecting planets using Doppler shift works. Use the arrow keys in "slide show mode" of PowerPoint to switch back and forth between the "blue shift" and the "red shift."

EXTRAS: Many planets outside our solar system have been discovered with this technique. Because planets close to their stars complete a cycle around their stars faster and because massive planets tug harder on their stars and cause the biggest Doppler shifts, most of the extrasolar planets discovered from the ground are massive and located close to their stars. Also,

if a planet's orbit is tilted 90 degrees to our line of sight, no Doppler shift will be seen in the star's spectrum no matter how massive the planet is.



The Kepler spacecraft is able to find smaller planets passing across their parent star by detecting transits.

A transit occurs when a planet crosses the line of sight between an observer and a star and blocks a small amount of light from the star, causing the light from the star to dim slightly for a few hours.

A large planet, like Jupiter, will cause a much larger drop in light than an Earth-size planet.

Slide 7



But stars are very far away. Many light years away. So let's move this star away.
(Moving star away for the next few slides)

Slide 8



A little farther...
(moving away)

Slide 9



And farther...
(moving away)

Slide 10



...and farther...
(moving away)

Slide 11



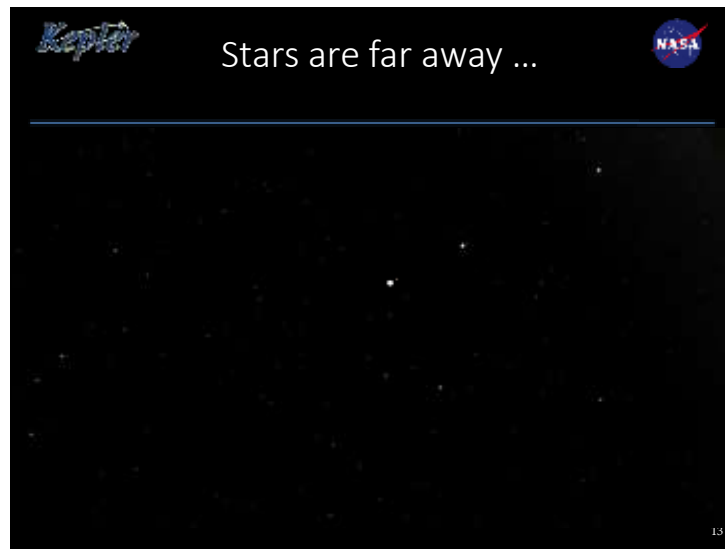
(moving away)

Slide 12



...and even farther...

Slide 13

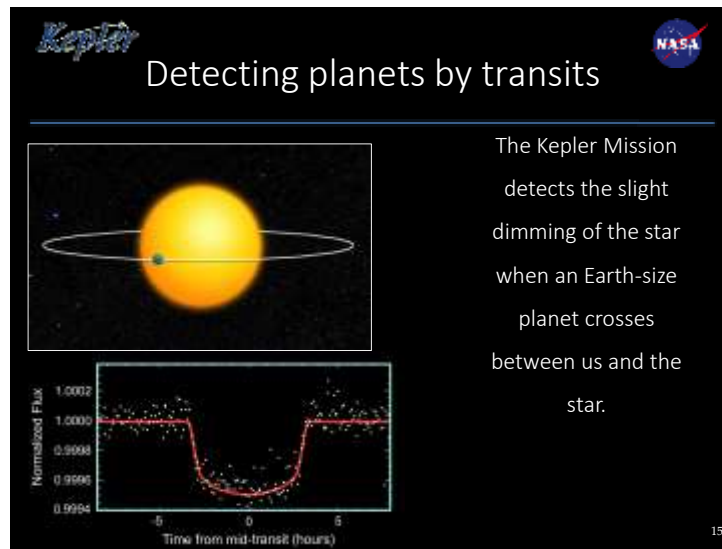


(moving away)

Slide 14



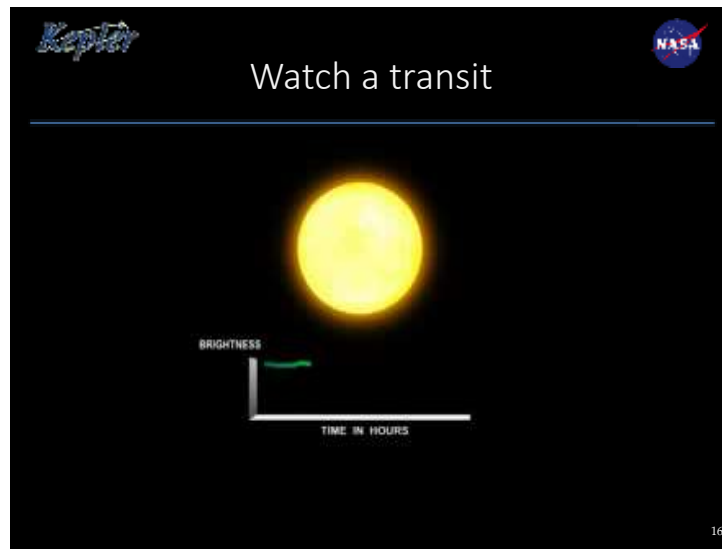
Can you see the planet moving across this star?
(no)



The Kepler Mission detects the slight dimming of the star when an Earth-size planet crosses between us and the star.

What Kepler does is watch for the slight dip in the light from a star caused by a planet passing between us and its parent star.

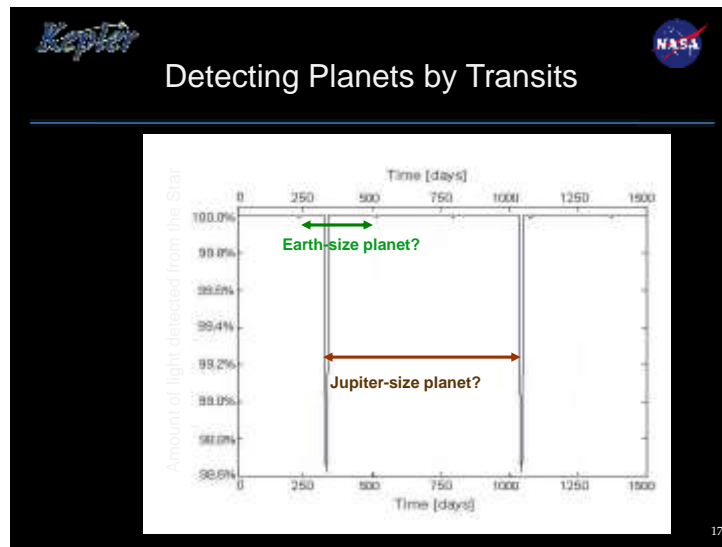
For an Earth-size planetary transit – it's about the same as the amount of light "blocked" or diminished if a ladybug were to walk across a searchlight.



You can also see the transit detection method in action via this video.

(Click the video thumbnail to begin.)

Notice how the light curve shown on the bottom drops as the planet transits its star, and then how the curve rises again after the planet exits the face of the star.



Here is an example of a star that Kepler might have watched. (1500 days is a little over four years). This star looks like it might have two transiting planets. Can you see them both?

This shows that we started watching the star here. (Indicate the zero on the x- axis)

On the left (indicate the y-axis), this shows how much light from the star is being detected. At 100%, no planets are transiting.

After about 325 days, we detect a drop in the light of about 1.4% from the star. Then about 700 days later, another drop in light of the same amount! Is this a big planet?

<CLICK>

Here's a potential planet about the size of Jupiter crossing between us and the star. This might be a planet orbiting the star about every 700 days.

But where's the other planet?

<CLICK>

Can you see the drop in light now? What size planet is that one?



<CLICK>

That looks like an Earth-size planet! It is causing a drop in light of 1/100th of a percent!

How many days does it take to orbit? –


Right, a little over 250 days. How many more times did Kepler detect the same drop in light from this star during the four-year period?

Yes, 3 more times!


 

System orientation!


For which of these systems would Kepler be able to detect transiting planets?



A



B



C

B. The star's planets must orbit the star edge-on from our viewpoint!
Not all planetary orbits are aligned this way.
So we must watch thousands of stars to find several that are correctly oriented.

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But only some planetary systems will be at the right angle from our point of view. Which one is it?

<CLICK>

(Read answer on slide)

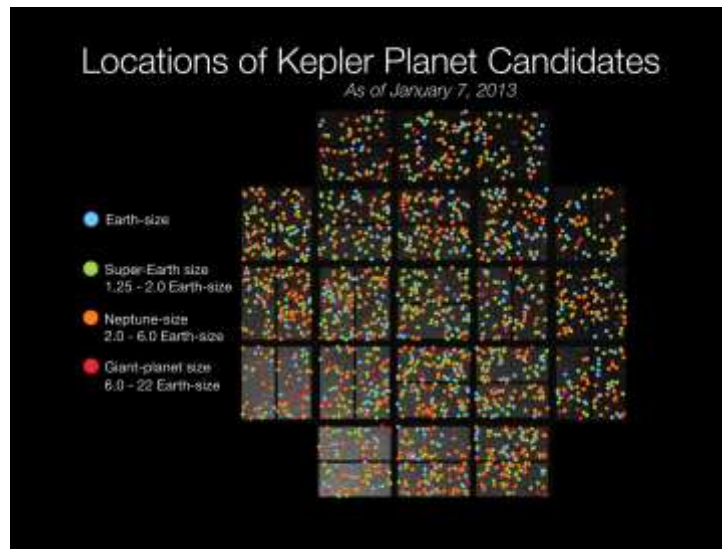


Here's the Summer Triangle.

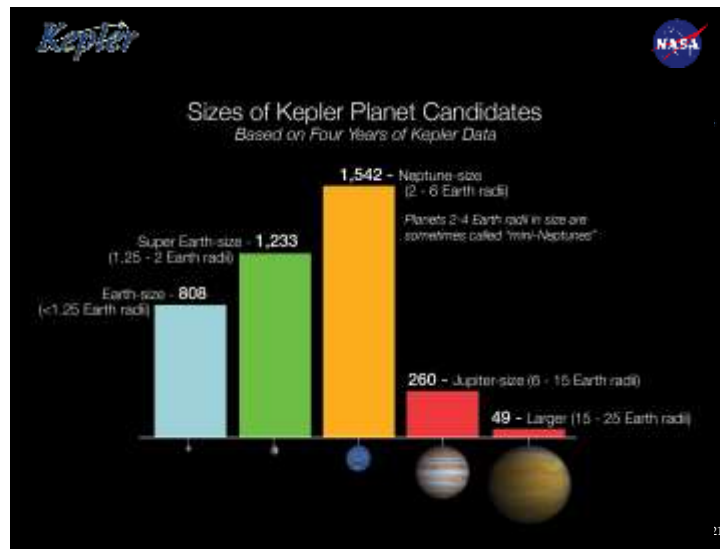
Kepler observed more than 150,000 stars for four years, from 2009 to 2013.

The field of view located between two of the stars (Vega and Deneb) in the Summer Triangle, just above the plane of the Milky Way. It's about an area of the sky the size of your fist held at arm's length.



Milky Way image courtesy Carter Roberts, Eastbay Astronomical Society



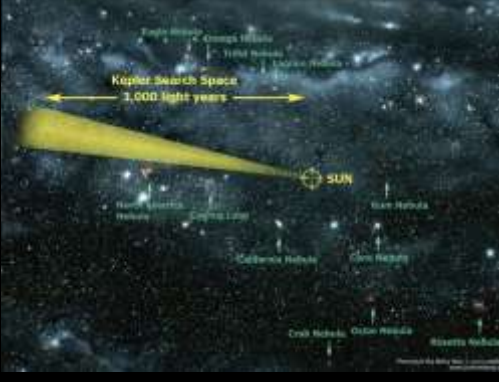
These are the locations of the Kepler planet candidates in its original field of view. They are color coded by planet size (diameter). Scientists working with the Kepler Mission estimate that about 90% of the planet candidates will be confirmed as planets, rather than as “false positives.”



The Kepler Mission has found many potential planets. These are called “planet candidates” and await confirmation by other methods. Over the 4 years of the Mission, more and more small planets—Earth-size planets—have been found, and scientists expect more small planet candidates to be discovered as more of the data is fully analyzed. Small planets are very likely the most common sort of planet in the galaxy. Just as small stars—like red dwarfs—are much more common than the largest stars, the blue giants.



What did Kepler do in its original mission?



Launch:
March 6, 2009

Simultaneously monitored more than 150,000 stars continuously for four years in an 10 by 10 degree area of sky.

Detected three or more transits for each planet discovered.

The probability that a planet in the habitable zone is aligned properly to transit the star is about 0.5%.


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The probability that the orbits are properly aligned to observe a transit is about one-half of one percent when the exoplanet's orbit is like Earth's orbit around our Sun. So, for example, if each of 150,000 stars had at least one Earth-size planet orbiting at Earth's distance from the Sun, Kepler would statistically detect about 750 of those exoplanets.



SCRIPT:


Kepler used transits to detect Earth-size planets orbiting in the habitable zone of sun-like stars.
Let's see what each of these points means.

Kepler Why "Earth-size" planets? 

If a planet is:

- Too small—less than 1/2 the mass of Earth—like Mercury or Mars:
Not enough gravity to hold onto a life-sustaining atmosphere
- Too big—more than about 10 times the mass of Earth—like Jupiter and Neptune:
Enough gravity to hold onto light gases—hydrogen and helium—and turn into a gas giant planet.

Earth Mars



Jupiter

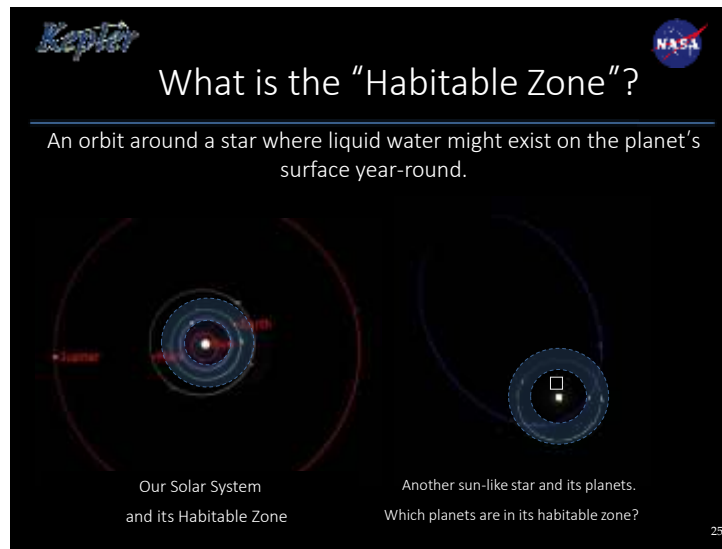
24

In NASA's quest to search for life elsewhere in the universe, why would "Earth-size" planets be the best to find?

If a planet is too small, it cannot hang onto a life-sustaining atmosphere.

<CLICK>

Too big and you've got a gas giant.



What is being defined as the “habitable zone”? The “habitable zone” is where evidence of life might be detected across the vastness of space. What's the most common substance in most living things? Water! And not just any water, but liquid water -- not ice and not steam. So at what distance from the star might liquid water exist?

<CLICK>

Here is where it is in our Solar System.

Here's another system.

<CLICK>

Which planet is in the habitable zone in this system?



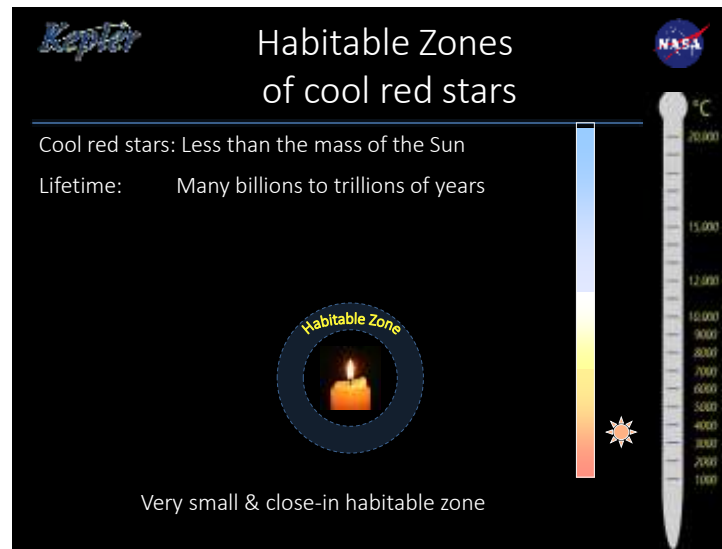
Let's use an analogy of a fire to represent the habitable zone.

Here are three different sized fires: a candle, a campfire, and a bonfire. These represent different masses of stars.

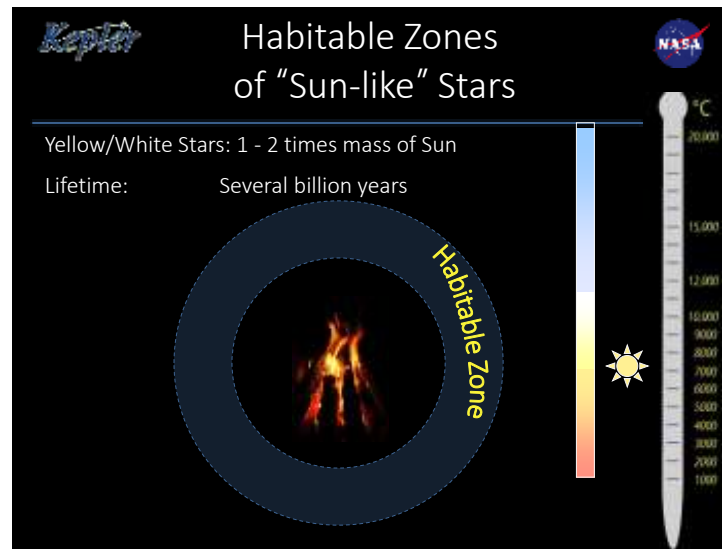
The habitable zone for a planet is analogous to where you can stand so you are not too hot or too cold.

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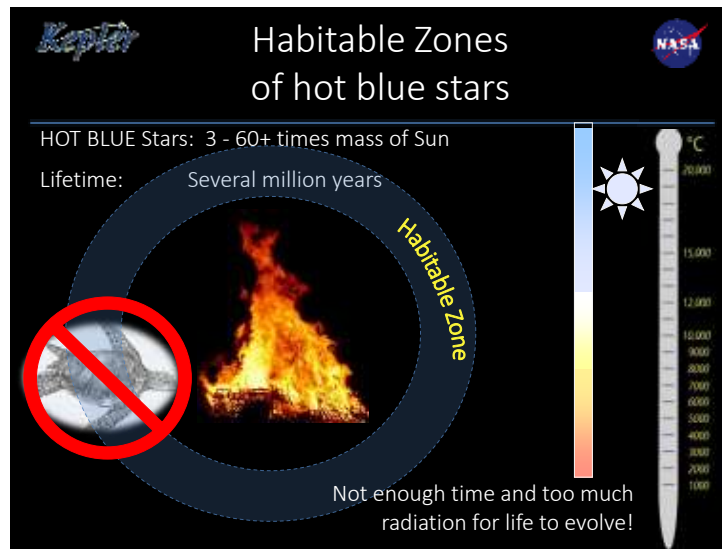
But this zone depends on the mass and type of star.



A small cool red star has a very small and close-in habitable zone. These stars live for billions to trillions of years.



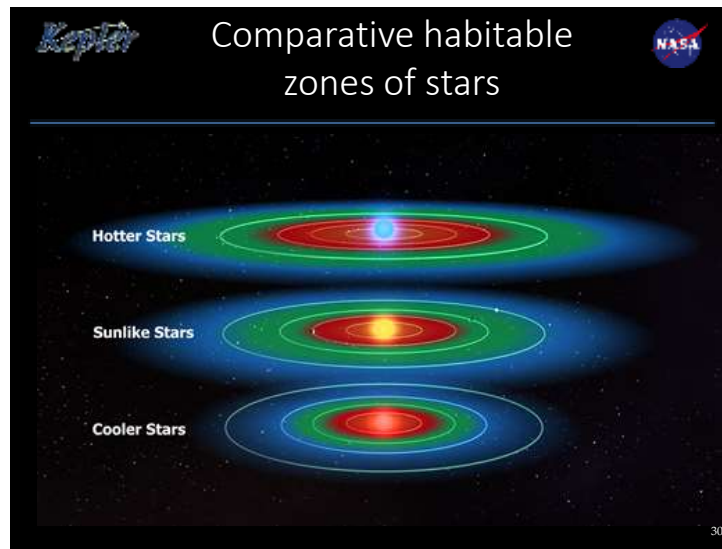
For a star like our Sun, the habitable zone is a little farther away. These stars live for a few billion years – enough time for diverse forms of life to evolve.




A hot, bluish star only lives a few million years – not enough time for life forms to evolve on its planets.

<CLICK>


A major problem with massive stars, beyond their short lifetimes, is that they expend most of their energy as ultraviolet radiation – which is very destructive of organic molecules on the surface of planets, and makes it difficult to evolve complex molecules, which would lead to simple life forms.



This graphic shows the three different types of stars and their habitable zones in green. The red areas are too hot for liquid water to exist and the blue areas are too cold.

Kaplan What else makes a planet "habitable"? 

Would it matter if you wore a light jacket?
How about a very heavy jacket?



It also matters if a planet has an atmosphere and how thick that atmosphere is.

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Other factors that determines the habitability of a planet is its surface temperature, whether or not it has liquid water, and does it have an atmosphere? If it were a very cold night and all you were wearing was a t-shirt, would that affect where you would be comfortable around the fire? How about if you were wearing a parka? What you are wearing is like the atmosphere around a planet.



Here's our Sun.

<CLICK>

This person is like Mercury. Virtually no atmosphere and very close to the Sun. Like being lightly dressed in the desert. Daytime temperature of Mercury is 660 F (250 C) and night side is about -300 F (-180 C). Could liquid water exist on its surface?

What is the next planet out from the Sun?

<CLICK>

A person wearing a heavy jacket and too near a camp fire, is like Venus – it has too heavy an atmosphere and is too close to the Sun. The temperature of Venus is always about 880 degrees F (470 degrees C). By comparison, how hot is your oven when you bake a cake or roast a turkey?

<CLICK> Earth's temperature varies, but does liquid water always exist somewhere on its surface?

The Moon is essentially the same distance from the Sun as Earth – but has no life and no liquid water - what's different?

Right, no atmosphere because the daytime temperature on the Moon: 273 F (134 C). The nighttime temperature on the Moon is -274 F (-170 C)

<CLICK>

A chilled person who is wearing a T-shirt in the Arctic is like Mars, which has very little atmosphere. The temperature at the planet's surface varies widely during the course of a Martian

day, from about -125 F (-87 °C) just before dawn to about -4 F (-20 °C) in the afternoon. Do you think that Mars has liquid water?

<CLICK>

It's not just the distance from the star that determines habitability. As hinted at earlier, the atmosphere of a planet-or lack of one-makes a huge difference in a planet's ability to support life as we know it.

Notes:

Hot Mercury Man image courtesy Flickr User Mamboman1

<http://www.flickr.com/photos/mamboman/>

Relaxing folks (Earth) image courtesy Flickr User Ed Yourdon

<http://www.flickr.com/photos/yourdon/>



The Kepler telescope observed just a small sample of our whole Galaxy during its original mission.

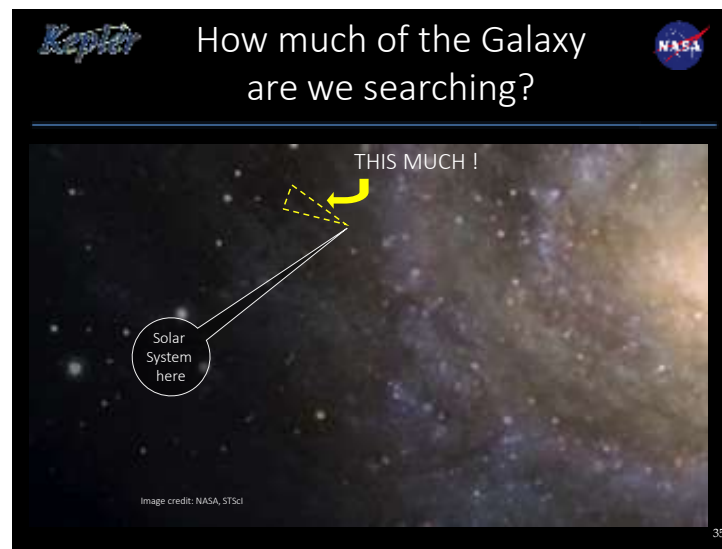
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It focused on stars in the same general area as our Sun. Let's zoom in a little.

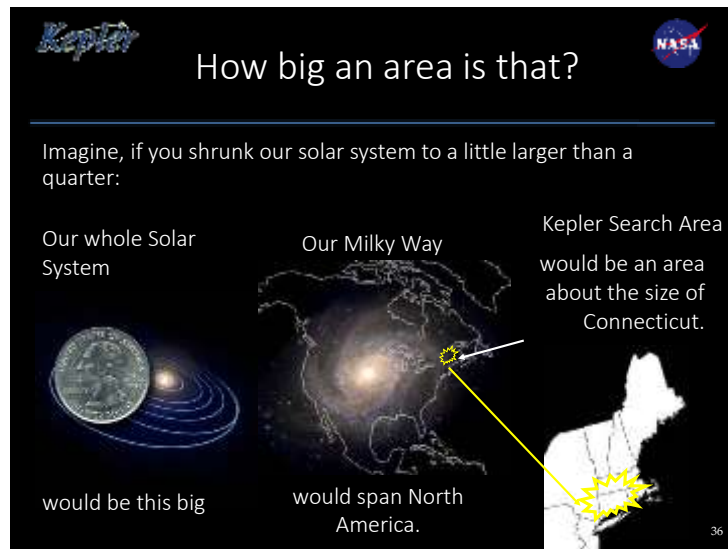
Slide 34



Zooming in more



Kepler has observed about this much of our Galaxy, <CLICK>



<CLICK>

Imagine, if you shrunk our solar system to be a little larger than a quarter.

Then, our Solar System would be this big. <CLICK>

Our Milky Way Galaxy would span North America <CLICK>

Kepler monitored stars in an area about the size of Connecticut <CLICK> (within about 3000 light years from Earth).

Kepler 

What's next?

When Kepler detects potential planets.....

follow-up work is done by other methods to make sure its really a planet...



... and other observations try to detect evidence of life!

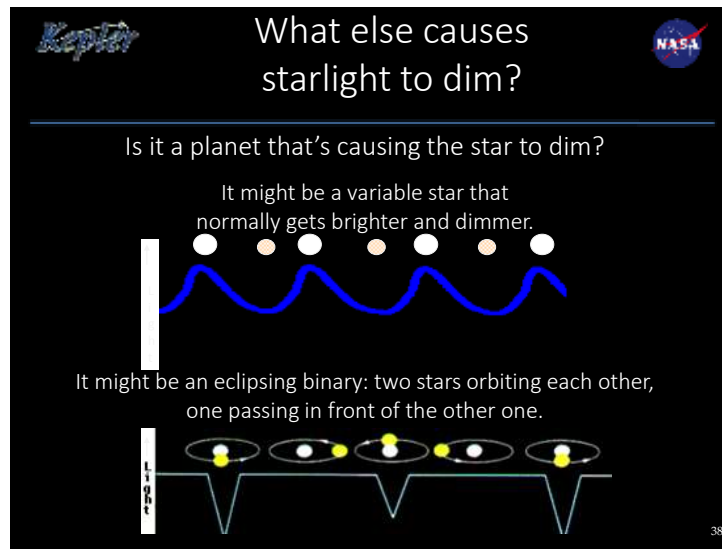
Credit Earth: NASA Goddard Space Flight Center <http://visibleearth.nasa.gov/>

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After Kepler detected some potential transits,

<CLICK>

follow up work was done (and continues to be done) to confirm that it is a transiting planet and to look for evidence of life.



When we say “follow-up work to make sure it’s a planet”, what else can cause a star to dim?

<CLICK> variable stars

<CLICK> two stars orbiting each other.

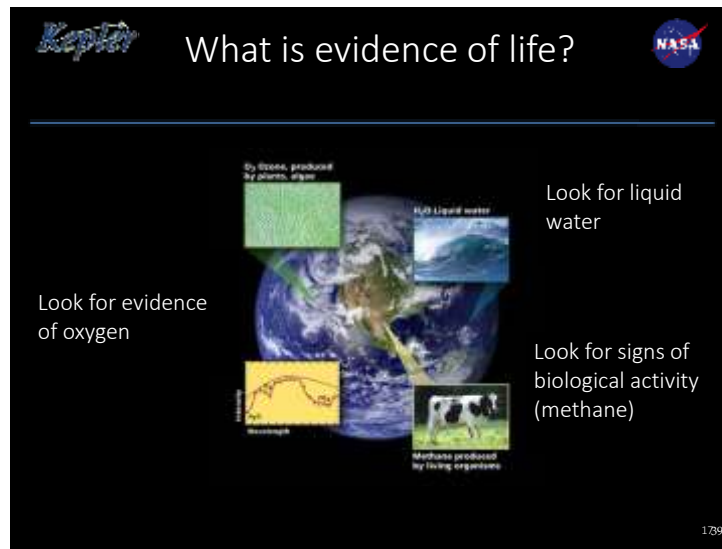
Other instruments and telescopes will verify - or not - the transit candidates Kepler finds.

Credit: Eclipsing binary illustration from Goddard Space Flight Center: Imagine the Universe:

http://imagine.gsfc.nasa.gov/docs/teachers/lessons/star_size/star_orbital.html

Eclipsing binary illustration from Goddard Space Flight Center: Imagine the Universe.

http://imagine.gsfc.nasa.gov/docs/teachers/lessons/star_size/star_orbital.html



And how will scientists know a planet might support life?

Even if a small Earth-size planet is in the habitable zone,

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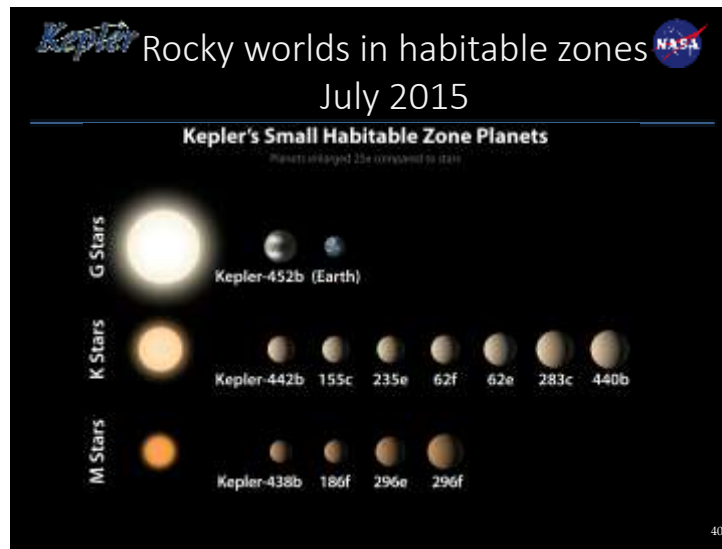
it has to have certain gases in its atmosphere and liquid water on its surface

<CLICK> to create and support life. There should be verifiable evidence of oxygen in its atmosphere and liquid water on its surface,

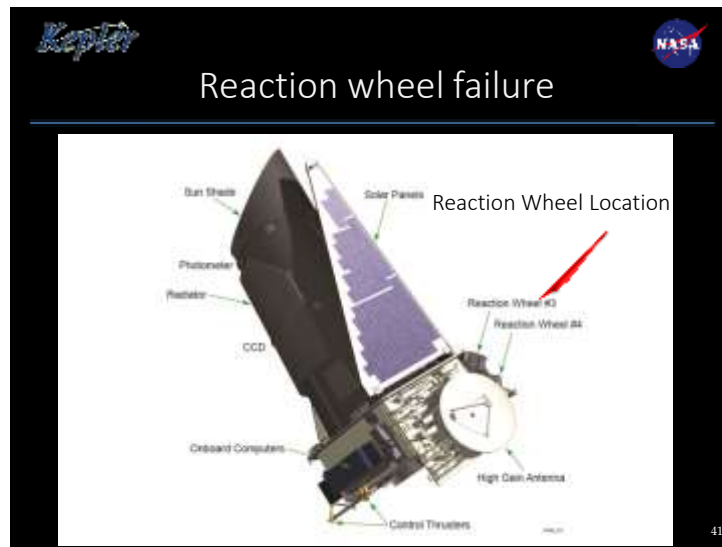
<CLICK> to support viable life forms.

Extra Info: The recent discoveries of so-called extremophile forms of life that survive or even flourish in environments from polar ice cores to boiling, sulfurous pools in deep, dark ocean trenches has stretched our understanding of the conditions under which life can exist and, perhaps, even evolve.

But, as far as we know right now, we would not be able to detect this kind of life across the vastness of space.



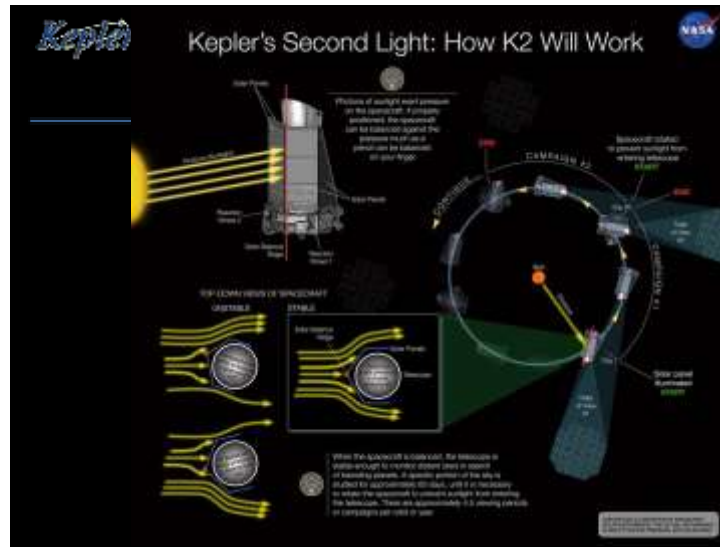
As of July 2015, Kepler has found 12 small worlds (no more than twice the size of Earth) in the habitable zones of their parent stars. These may be rocky worlds. One world, Kepler-452b, even orbits in the habitable zone of a star very much like our Sun! It is not an exact match to Earth, but it can be considered a slightly larger, older cousin to our world. Kepler 186-f is an Earth-sized rocky world in the habitable zone of its star, though its parent star is a small red dwarf, much different than our own Sun.



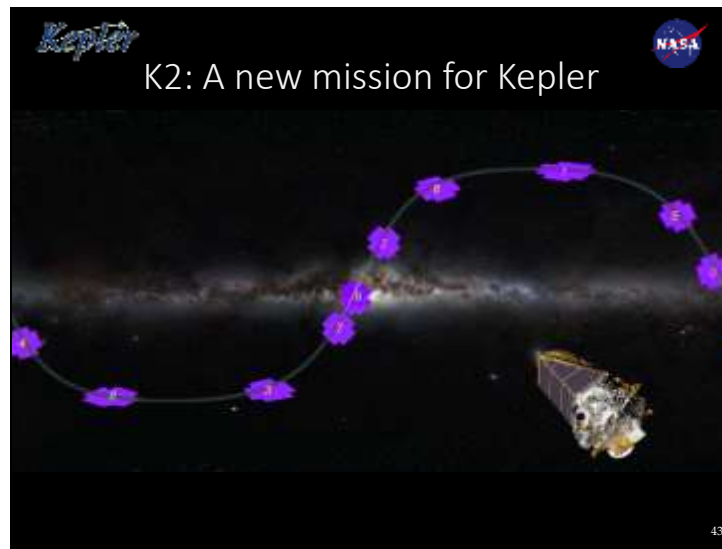
In May 2013 Kepler suddenly went into safe mode. Engineers found that Reaction Wheel #4 had failed. Combined with the earlier failure of another reaction wheel, this meant that 2 out of 4 of its reaction wheels were out of commission. Kepler needed a minimum of three wheels to maintain its high precision pointing accuracy. Could Kepler continue to perform science in this state?

Additional Info: Reaction wheels are stabilizers that operate like gyroscopes, rapidly spinning to maintain the spacecraft's position without having to fire thrusters and which offer fine control over its movements and position.

Image credit: Ball Aerospace

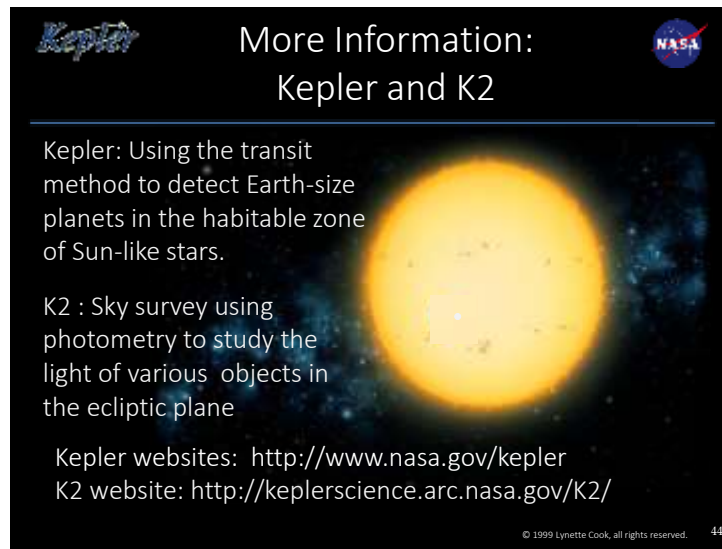



Kepler engineers figured out a way to keep the craft pointed in one spot for months at a time by using its last two reaction wheels plus the pressure from the solar wind. However, due to constraints with this new method, they could no longer point Kepler at its original target area. The spacecraft was re-purposed, and the mission renamed K2.



In June of 2014, the K2 mission became fully operational. K2 uses the incredible light sensitivity of the Kepler spacecraft to survey the sky near the ecliptic using its excellent photometer. Because Kepler uses the solar wind as a “third gyroscope” to sustain pointing on target, K2 focuses on one section of the sky for about 3 months before moving to its next target. The spacecraft has to re-orient every three months to keep sunlight from entering the telescope. K2 observes many kinds of targets, including supernova, variable stars, and of course, exoplanet transits. As of July, 2015, K2 identified more than 20 exoplanet candidates.

A guest observer program allows outside organizations to suggest targets for the K2 mission, and all the data will be publicly available.



Kepler More Information: 

Kepler: Using the transit method to detect Earth-size planets in the habitable zone of Sun-like stars.

K2 : Sky survey using photometry to study the light of various objects in the ecliptic plane

Kepler websites: <http://www.nasa.gov/kepler>
K2 website: <http://keplerscience.arc.nasa.gov/K2/>

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SCRIPT:

So here is a review of the Kepler missions:

<CLICK> (planet appears over star)

<CLICK>

Kepler: To use transits to detect Earth-size planets orbiting in the habitable zone of Sun-like stars.

<CLICK>

K2: Sky Survey using photometry to study the light of various objects in the plane of the ecliptic

You can check out more information about these amazing missions on their official websites.

<CLICK>

Optional: So are you ready to go outside and look at the area of the sky Kepler is watching? What else will you find in the Summer Triangle when you look through the telescopes? Let's go see!